Reduction of biological production due to vigorous horizontal mixing in the Benguela upwelling system.

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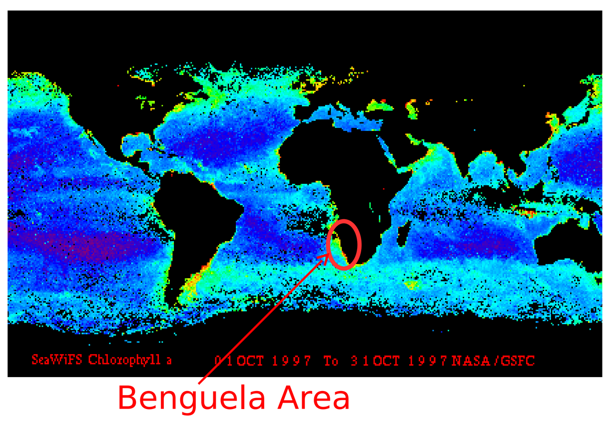
Abstract

We study the interplay of hydrodynamic transport and plankton dynamics in the Benguela upwelling system. A coupled system of oceanic flow and a simple biogeochemical model (NPZ type) is used. For the flow we use three different velocity fields: one derived from satellite data (altimeter and scatterometter) at 1/4˚, and the other two from a regional numerical model at 1/4˚ and 1/12˚ resolution. We study the effect of the horizontal transport on the dynamics of phytoplankton and compare simulations using the three differents velocity fields. We compute horizontal Finite Size Lyapunov Exponents (FSLEs) as a proxy of horizontal mixing and analyze their correlations with phytoplankton concentrations.

Coupling hydrodynamical and biological models in the Benguela

- Coupling between hydrodynamical and biological models: advection-reaction-diffusion system. This system is resolved using a semi-Lagrangian algorithm.
- The biological model is derived from Sandulescu et al. [2008] and describes the interaction of a three-level trophic chain (NPZ) in the mixed layer of the ocean (see below).
 Horizontal transport is explicitly taken into account in the 2D flow from satellite at 1/4^0 spatial resolution (Sudre and Morrow [2008]), and velocity data from the ROMS (Regional Ocean Modeling System) climatological numerical model at 1/4^0 and 1/12^0 spatial resolution.
- The advection is performed in 2D (ocean surface only) for both systems.

- The nutrient supply due to vertical mixing mimics the upwelling, and it is modeled as a source term in the nutrient part of nutrient equation.
- We add also an eddy diffusion process acting on plankton and nutrients concentrations to incorporate the small-scale turbulence, which is not explicitly taken into account by the velocity fields used. The diffusion coefficient, D, is given by Okubo's formula and the value is corresponding to the length scale of the velocity data (spatial resolution).
- The biological model needs a 2 months spin-up to reach its equilibrium.



Benguela Area

Advection-Reaction-Diffusion Equations

$$\frac{\partial N}{\partial t} + \mathbf{v}\nabla N = F_N + D\nabla^2 N$$
$$\frac{\partial P}{\partial t} + \mathbf{v}\nabla P = F_P + D\nabla^2 P$$
$$\frac{\partial Z}{\partial t} + \mathbf{v}\nabla Z = F_Z + D\nabla^2 Z$$

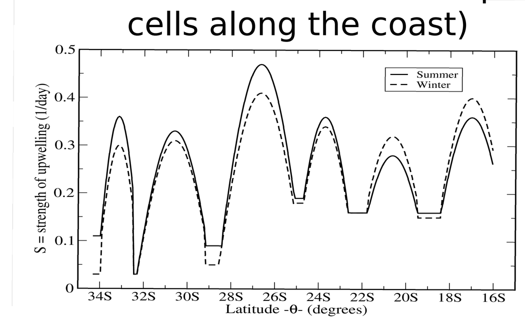
NPZ model

$$\frac{dN}{dt} = F_N = \Phi_N - \beta\frac{N}{\kappa_N + N}P + +\mu_N\left((1-\gamma)\frac{\alpha\eta P^2}{\alpha+\eta P^2}Z + \mu_P P + \mu_z Z^2\right)$$
$$\frac{dP}{dt} = F_P = \beta\frac{N}{\kappa_N + N}P - \frac{\alpha\eta P^2}{\alpha+\eta P^2}Z - \mu_P P$$
$$\frac{dZ}{dt} = F_Z = -\gamma\frac{\alpha\eta P^2}{\alpha+\eta P^2}Z - \mu_Z Z^2$$

Mixing term

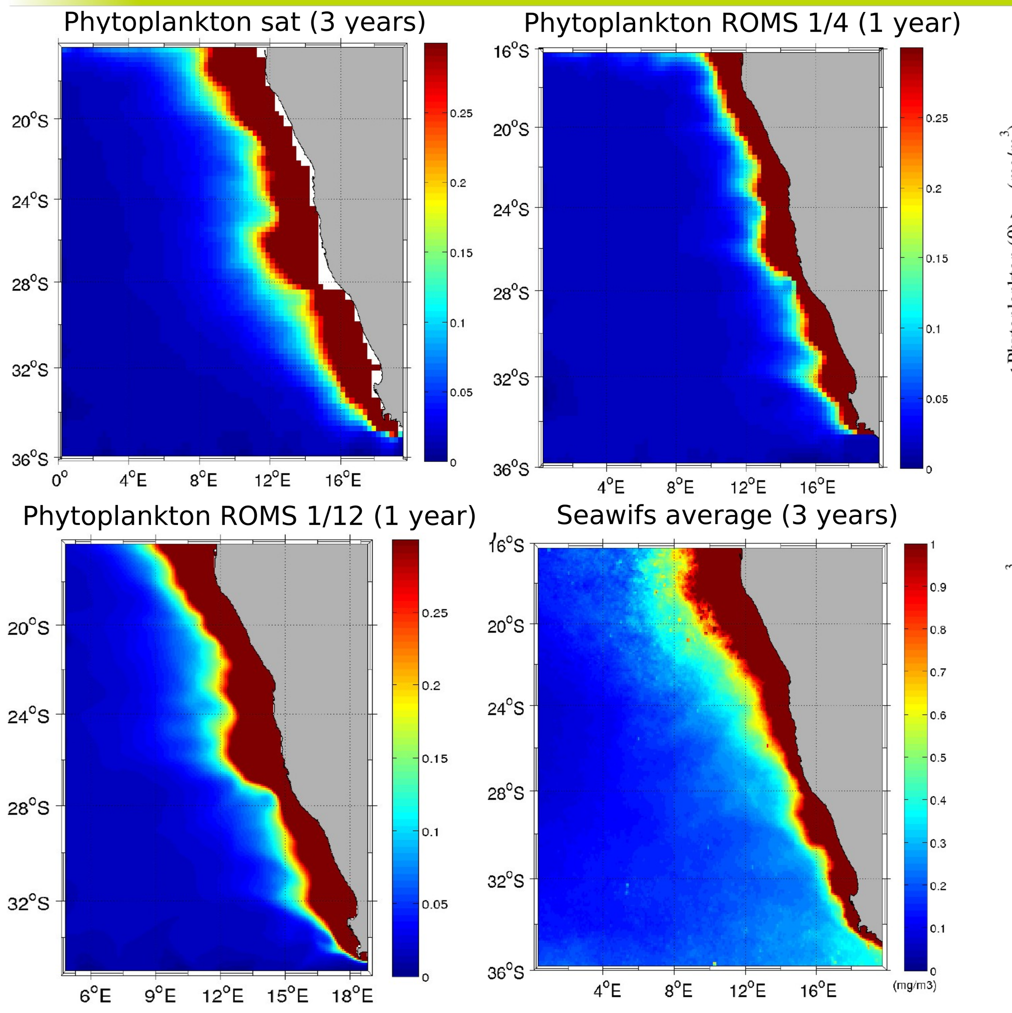
$$\Phi_N = S(x-y)(N_0 - N)$$

(S is the strength of the upwelling. We use seasonal values to mimic the upwelling cells along the coast)

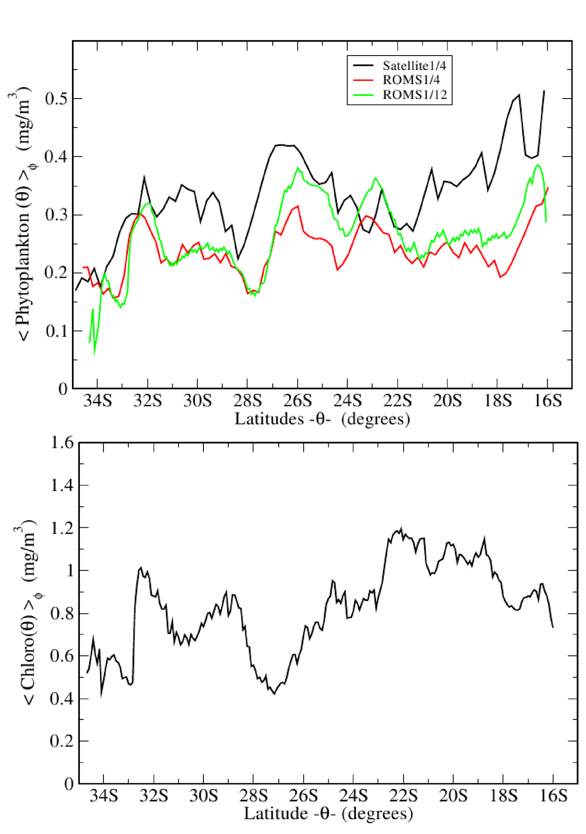


Spatial variability: comparison between time average of modelled Phytoplankton and Chlorophyll from SeaWiFS

Phytoplankton sat (3 years) — Phytoplankton ROMS 1/4 (1 year) — Phytoplankton ROMS 1/12 (1 year) — Seawifs average (3 years)



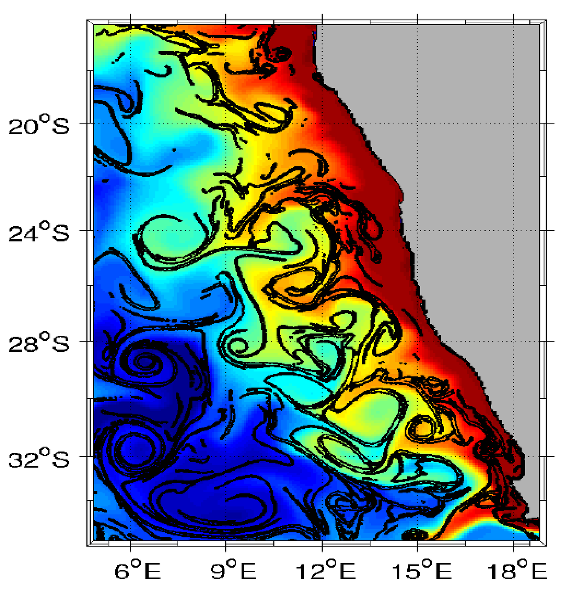
Zonal average of time average



·Slightly better agreement using ROMS velocity field (redand green line).

· Higher concentrations of chlorophyll at the coast, decreasing offshore. Chlorophyll concentrations are higher in the north than in the south.
 Phytoplankton decreases with latitud. General pattern quite well reproduced, but large differences in the range of chlorophyll concentrations (underestimation of the model).
· Low latitude: underestimation of the model (effect of the PAR not taken into account?)

FSLE superimposed on P concentrations from ROMS (1/12^0)

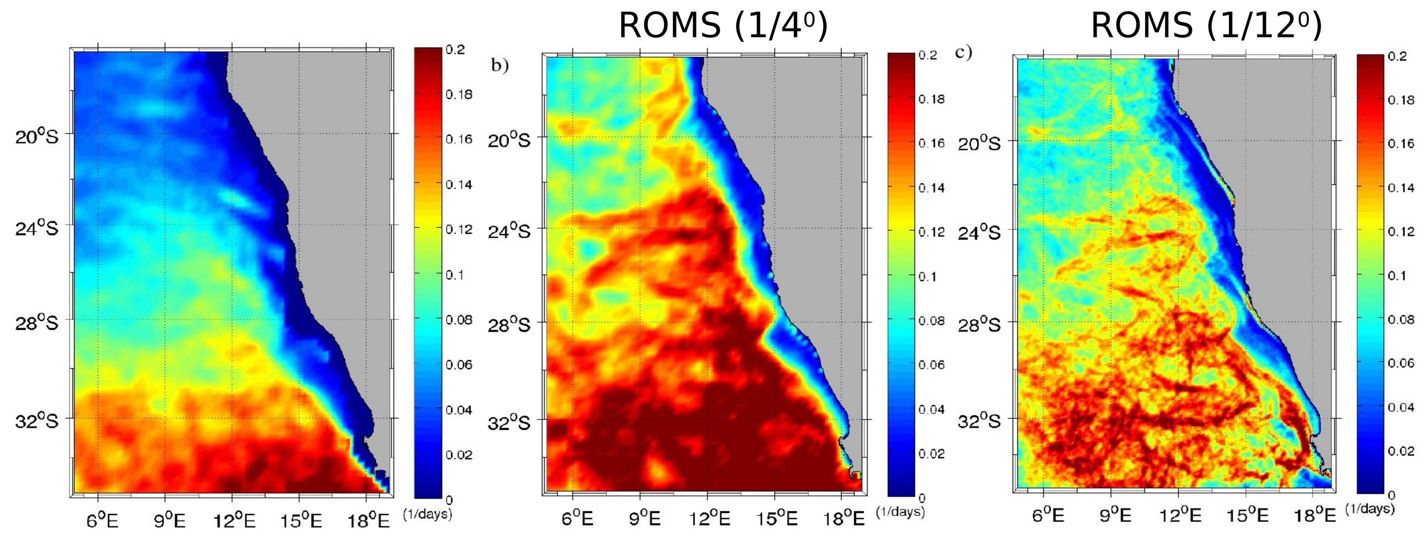


- Complex spatial structures in plankton concentrations (dynamics of the turbulent medium and of the marine ecosystem).
- Using ROMS1/12 velocity field, the structures are clearer since the flow is more turbulent and the spatial resolution is finer than the satellite velocity field.

Spatial variability: surface horizontal mixing from time average of Finite Size Lyapunov Exponents (FSLEs)

$$\lambda(\mathbf{x}, t, \delta_0, \delta_f) = \frac{1}{\tau}\log\frac{\delta_f}{\delta_0}$$

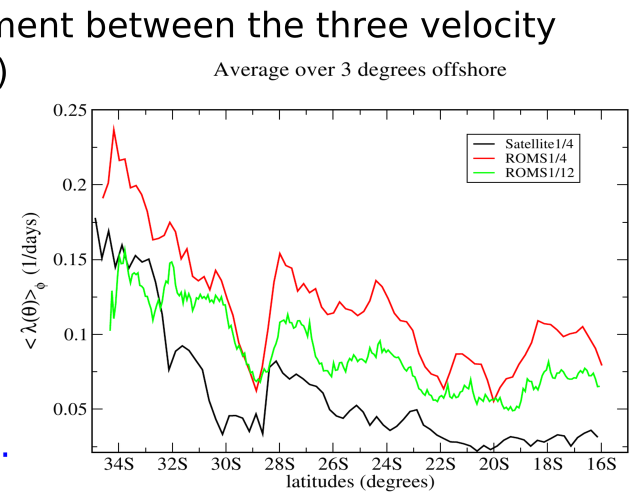
ROMS (1/4^0) — ROMS (1/12^0)



· Higher horizontal mixing in the southern Benguela than in the north in the three velocity fields. Southern system more turbulent than the northern one.
· Higher spatial averaged mixing in ROMS than in the satellite velocity field.
· Latitudinal variations of mixing in agreement between the three velocity field (although different spatial resolution)
·Horizontal mixing decreases as latitud decreases

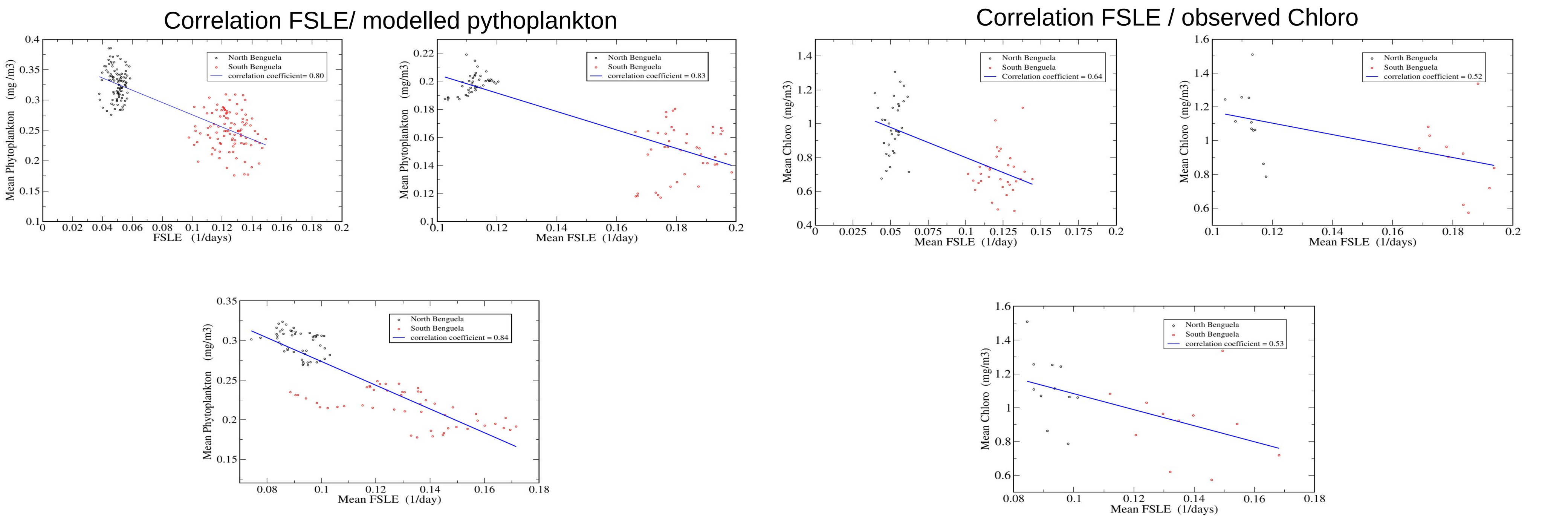
· High chloro / low mixing (north) and low mixing / high chloro (south): it suggests a spatial negative correlation between phytoplankton (Chlorophyll) and horizontal mixing (*Rossi et al [2008]*).

Average over 3 degrees offshore

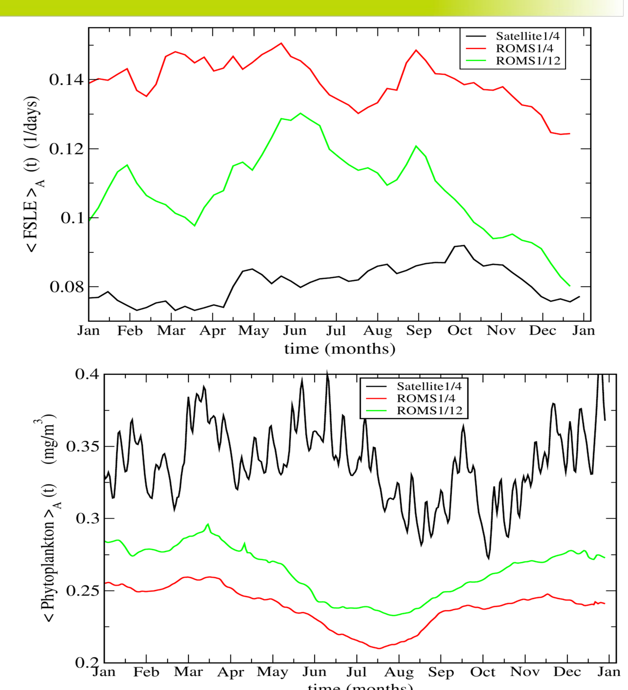


Correlation FSLE - phytoplankton concentrations: Effect of the velocity field?

Correlation FSLE/ modelled pythoplankton — Correlation FSLE / observed Chloro



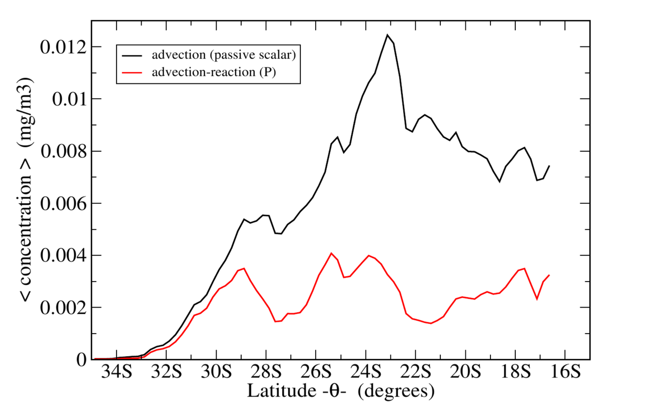
- The negative correlation between horizontal mixing and phytoplankton concentrations appears almost everywhere: robust inverse relationship. The higher the surfer stirring/mixing, the lower the biomass concentration.
- It is stronger when using satellite velocity field per subsystem → particular intrinsic hydrodynamic signature of the 2 subsystems not reproduced in the model?



- Negative correlation exists also in the annual cycle: winter = max mixing / min chlorophyll (lower nutrients input).

Sensitivity analysis

- Sensitivity of the relationship to the resolution of the velocity field and the dominant term (advection/diffusion/reaction)?
- The advection-only case reproduces well the samaller tracers concentrations in the southern domain
- The advection-reaction case presents a more constant latitudinal profile



Conclusions & Perspectives

- We reproduced the spatial and temporal variability of phytoplankton concentrations due to both dynamics of the flow and of the marine ecosystem.
- The model yields a spatial distribution of phytoplankton quite similar to the chlorophyll given by SeaWiFS. However the range of concentration is underestimated: parameters of the biological model? Initialization values? PAR effect? Introduction of a sinking term (varying spatially)?
- Horizontal mixing is higher in the south than in the north / chlorophyll concentrations are larger in the north than in the south Benguela.
- A negative correlation between horizontal mixing and phytoplankton concentrations is confirmed using the chlorophyll data as well as the modelled chlorophyll. However, this correlation is changing depending on the velocity field used and the area considered. Which processes are responsible? Effect of spatial resolution of the velocity field? Vertical dynamical constraints? Mixing intensity? Compressibility of the flow?
- Sensitivity studies confirm that the influence on the spatial distribution of phytoplankton in the south is 2D advection.

References:
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- *Sandulescu, M., López, C., Hernández-García E., and Feudel, U.*: Plankton blooms in vortices: the role of biological and hydrodynamics timescales. Nonlin. Processes Geophys., 14, 443-454, 2007.
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